A Progress Report on

sPHENIX-Forward Detectors

(for spin and heavy ion physics)

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03/06/2012 FSU Collaboration Meeting

Taking slides from: Joe Seele (RIKEN), Ming Liu (LANL)
Jin Huang (LANL) and Cesar Luiz da Silva (LANL)

sPHENIX-Forward task force: Joe, Ralf, Mathias (organizers) + many others.
Meetings: Tuesday 9:00pm EST.

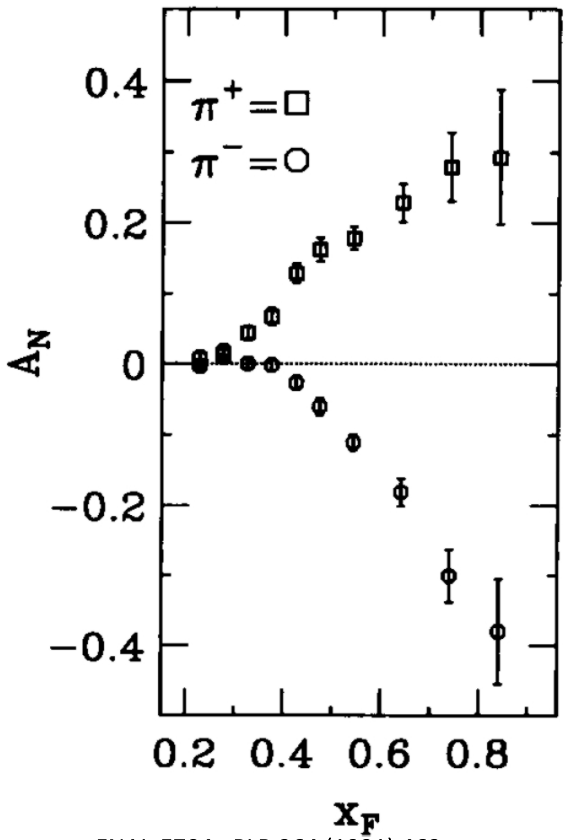
sPHENIX forward spin physics in p+p

With the sPHENIX forward detectors, we highlight three types of single-spin asymmetry measurements in p+p 200 GeV :

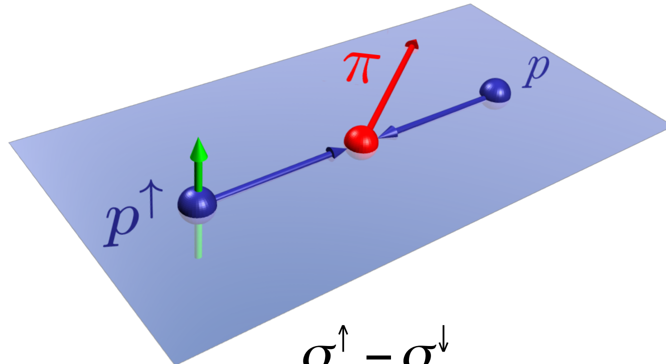
- Drell-Yan (e+e-) A_N. Sivers effect only. Sivers function change sign between DY and SIDIS.
- Jet A_N. Sivers effect only. Resolve disagreement of TMD factorization vs. twist-3 approaches.
- Hadron azimuthal distribution A_N inside a jet. Collins effect only, access quark transversity distributions.
- (Forward hadron, and prompt photon $A_{N.}$)

Quarks can tell left-right in $p\, p^{\uparrow} \to \pi X$

$p^{\uparrow} + p \to \pi + X$



FNAL-E704: PLB 264 (1991) 462.



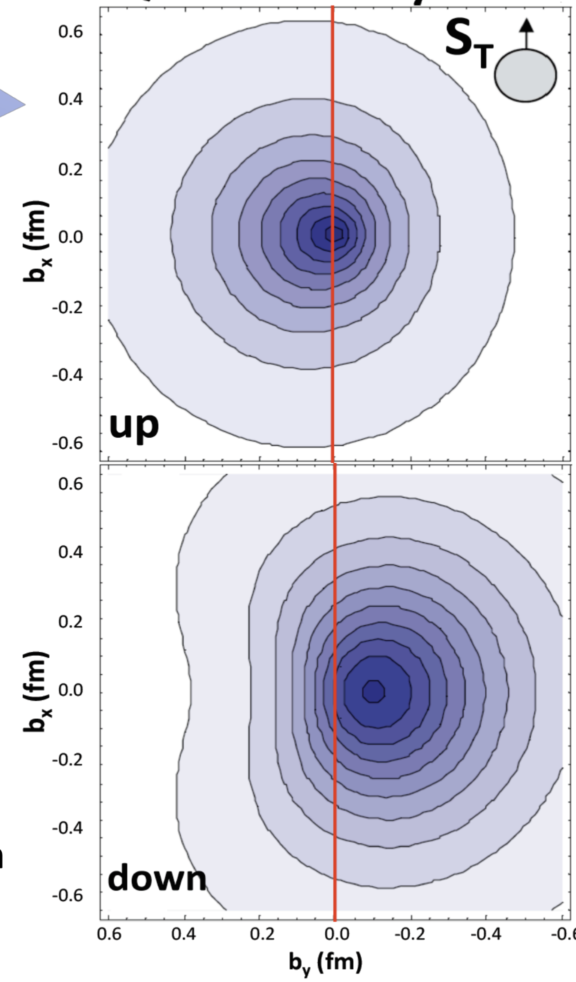
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$\pi^{+}\ (u\bar{d})$ favors left

$\pi^{-}\ (d\bar{u})$ favors right

One possible explanation (Sivers effect): quark's transverse motion generates a left-right bias.

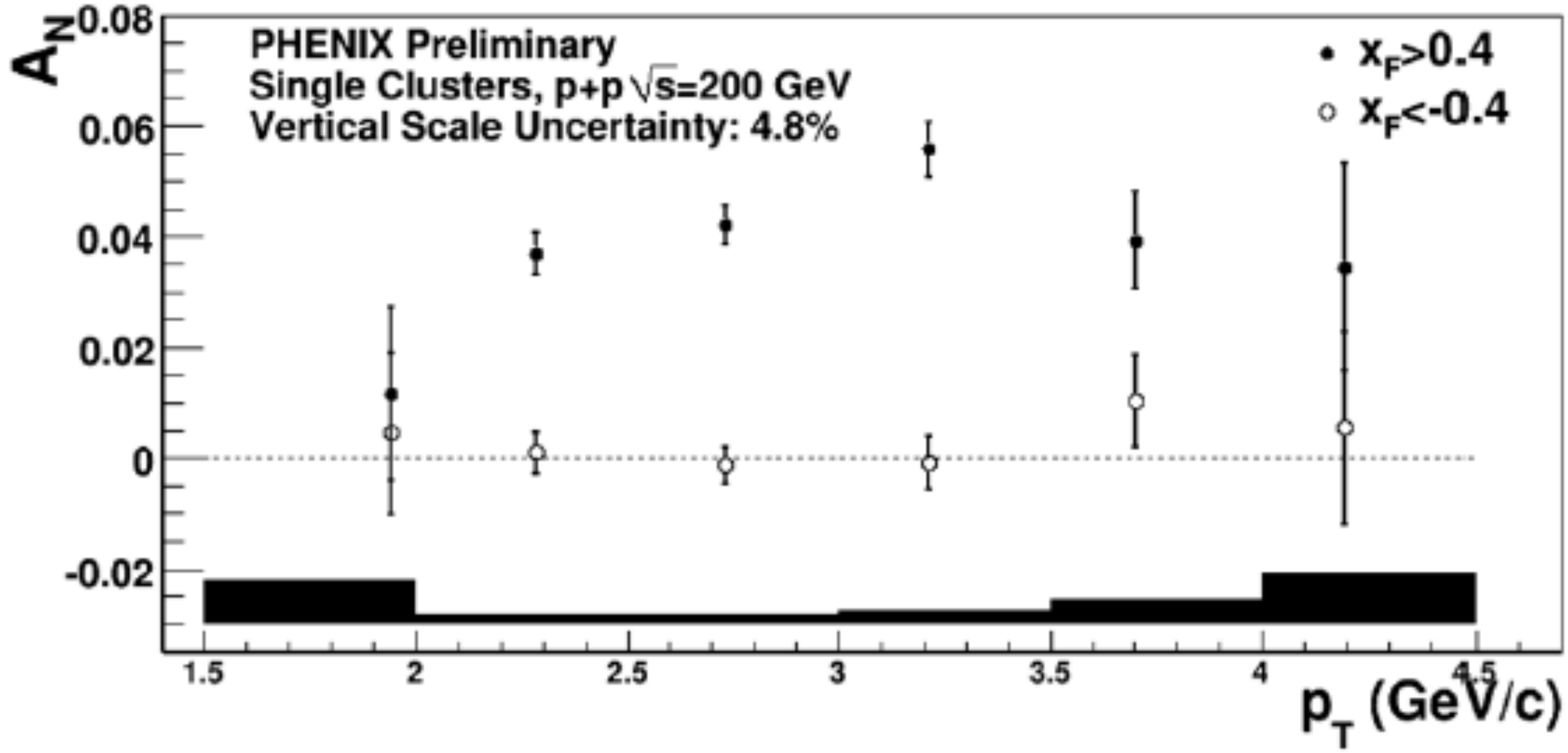
Quark Density in 2D



Lattice QCD PRL98:222001,2007.

up-quarks favor left (L_u>0), down-quarks favor right (L_d<0).

Large SSA in PHENIX: MPC Single Clusters



However, two mechanisms can not be distinguished in A_N of inclusive hadron production in p+p:

- Collins effect: quark transverse spin (transversity) generates a left-right bias through fragmentation.
- Sivers effect: quark transverse motion generates a left-right bias.

When the entire jet is captured, SSA effects are much easier to interpret:

- Hadron azimuthal A_N inside a jet: Collins effect only.
- Jet A_N: Sivers effect only.
- Direct photon A_N: Sivers effect only.
- Drell Yan A_N: Sivers effect only, with a sign flip vs SIDIS.

A Sign Mismatch of the Sivers function

Zhong-Bo Kang et al. arXiv:1103.1591

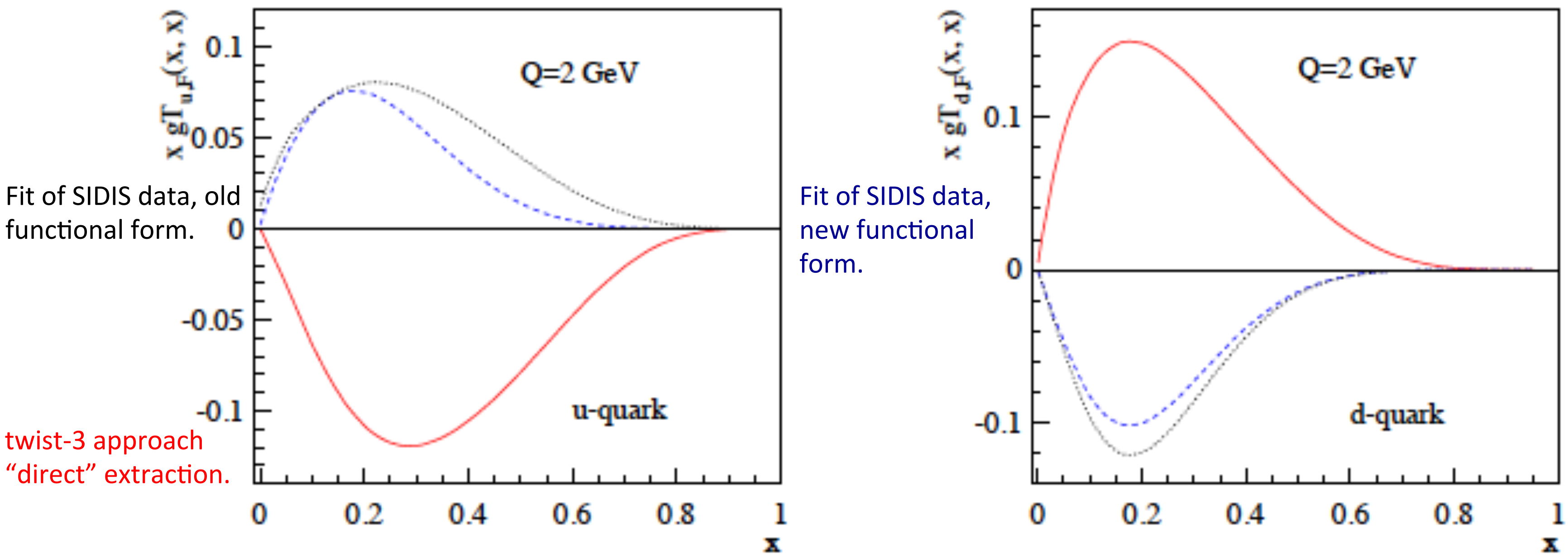
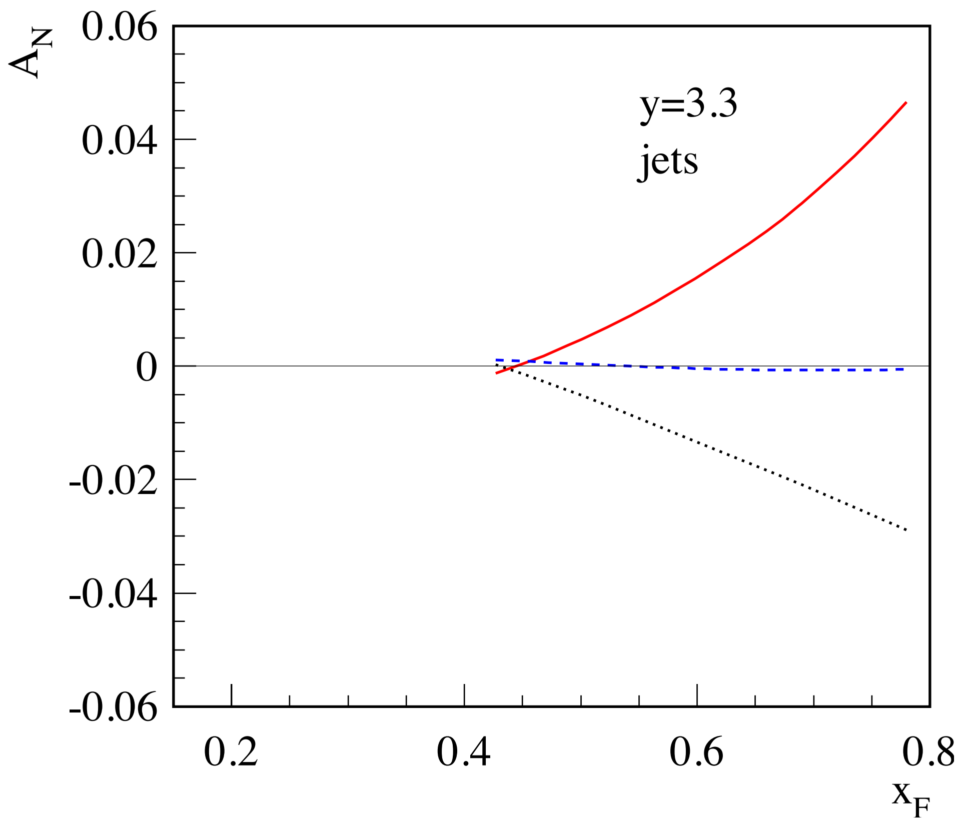


FIG. 1: The quark-gluon correlation function $gT_{q,F}(x,x)$ as a function of momentum fraction x for u-quarks (left) and d-quarks (right). The dashed (dotted) lines are $gT_{q,F}(x,x)|_{\text{new Sivers}}$ ($gT_{q,F}(x,x)|_{\text{old Sivers}}$) obtained by taking the $k_\perp$-moments of the corresponding quark Sivers functions according to the right-hand-side of Eq. (10). The solid lines represent the correlation functions extracted directly from data on SSAs for inclusive pion production in proton-proton collisions, $p^\uparrow p \to \pi + X$ [14], after correcting for the sign convention (see text).

Collinear twist-3 method in analyzing p+p data yields opposite signs of quark Sivers function moments compared to that from Semi-Inclusive Deep-Inelastic Scattering.

200 GeV p+p Jet A_N



twist-3 approach "direct" extraction.

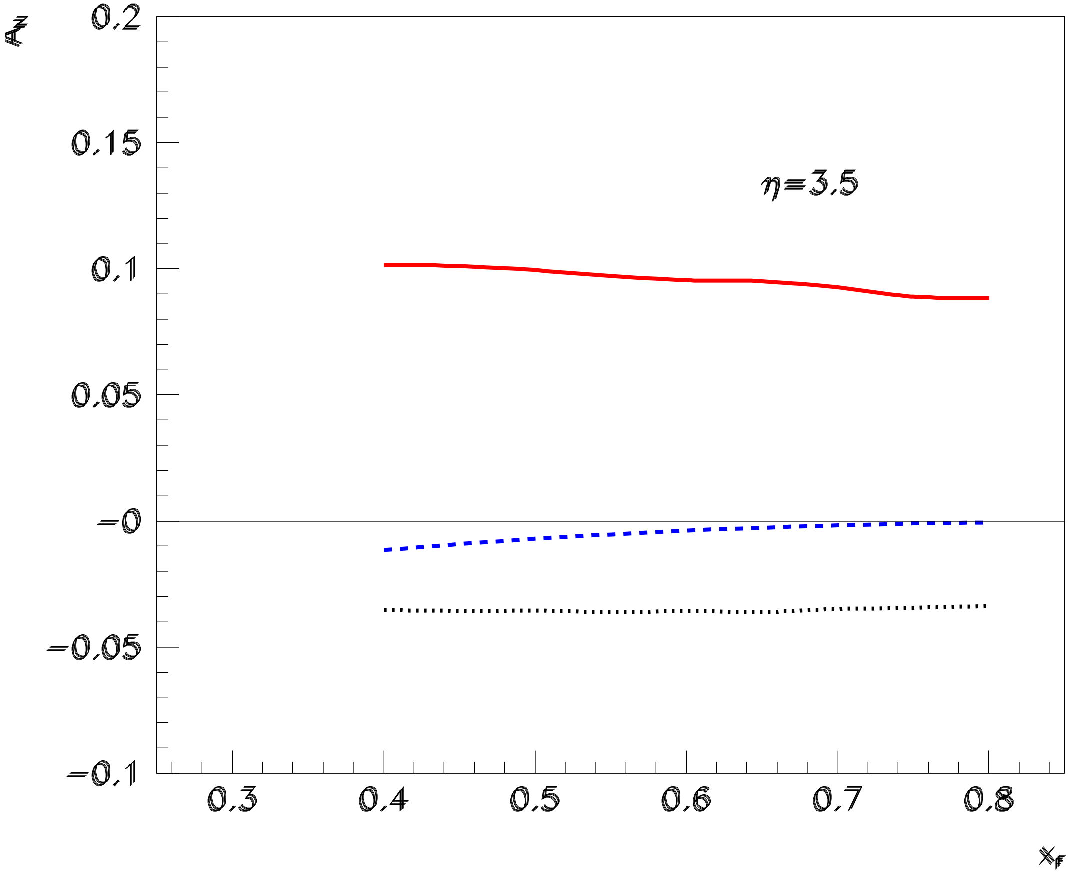
Fit of SIDIS data, new functional form.

Fit of SIDIS data, old functional form.

Zhong-Bo Kang et al. arXiv:1103.1591

sPHENIX can provide a clear answer to help resolving the puzzle on quark Sivers distributions.

200 GeV p+p Prompt Photon A_N



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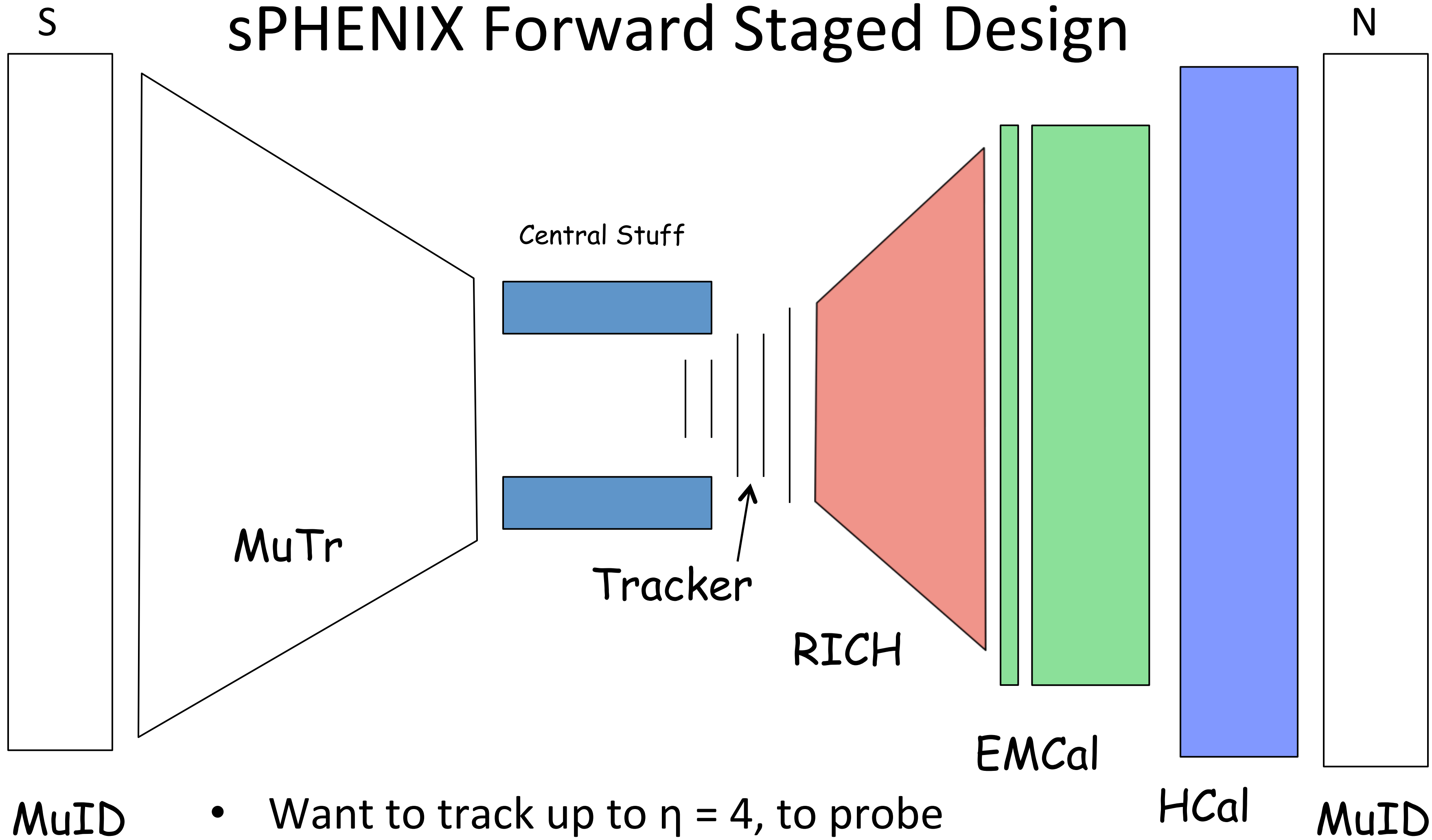
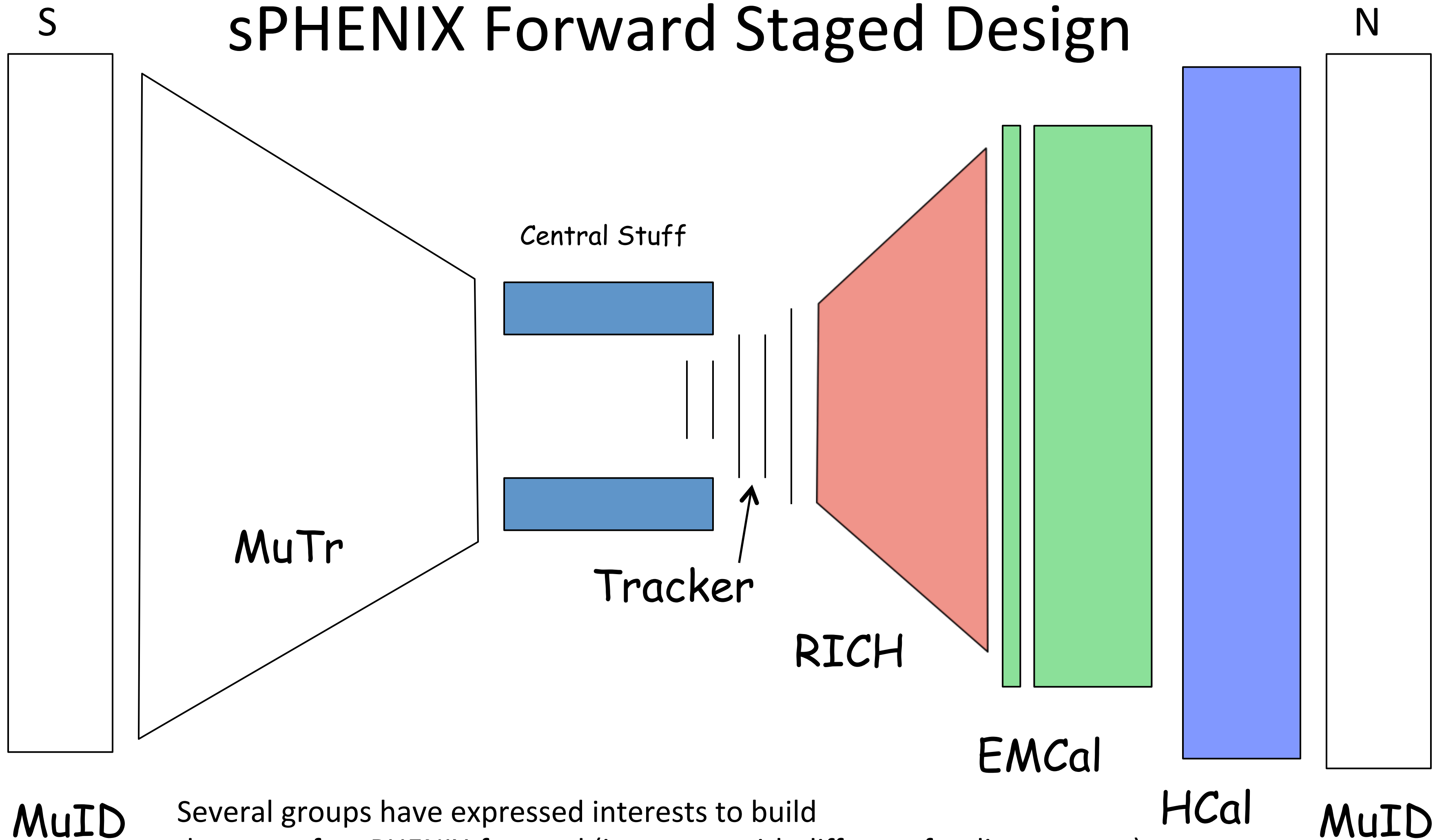
sPHENIX Forward Staged Design



- Want to track up to $\eta = 4$, to probe
  - High x_1 in Drell-Yan (e+e-) , low x_2 in p-A
- Most technical challenging part of the design
  - $\eta = 4$ -> 2 degree from beam
  - Magnetic bending ~ momentum analyzing power is limited

sPHENIX Forward Staged Design



Several groups have expressed interests to build detectors for sPHENIX-forward (in stages, with different funding sources)

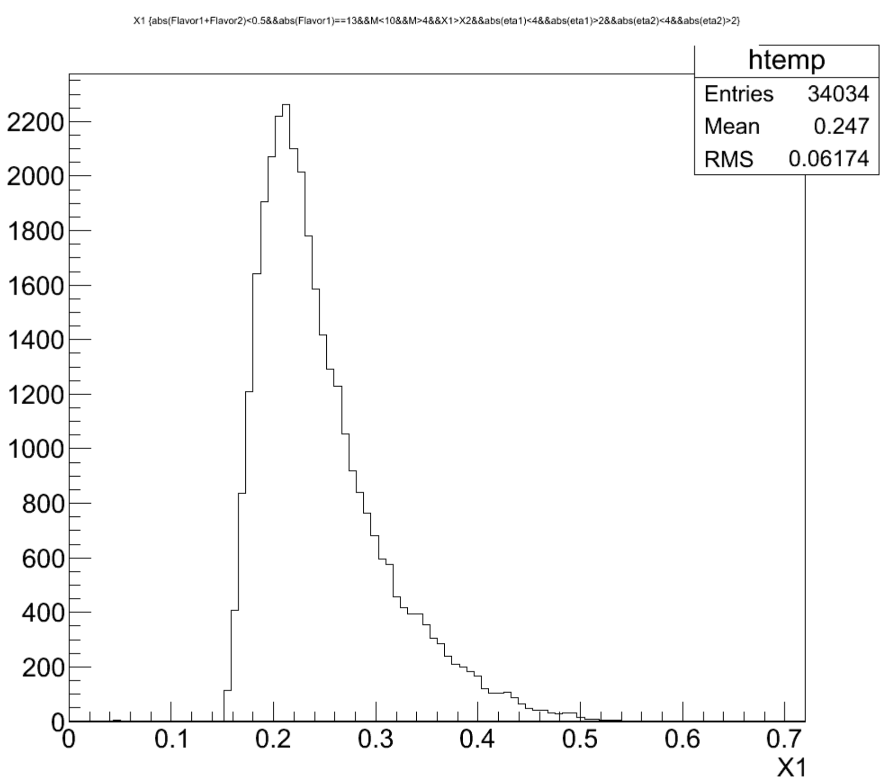
- Tracker, Hcal …
- Emcal, RICH …

- sPHENIX-Forward also fit for hadron detection in ePHENIX
- With an Emcal, it can also be the electron detector in ePHENIX, (along the e-beam side).

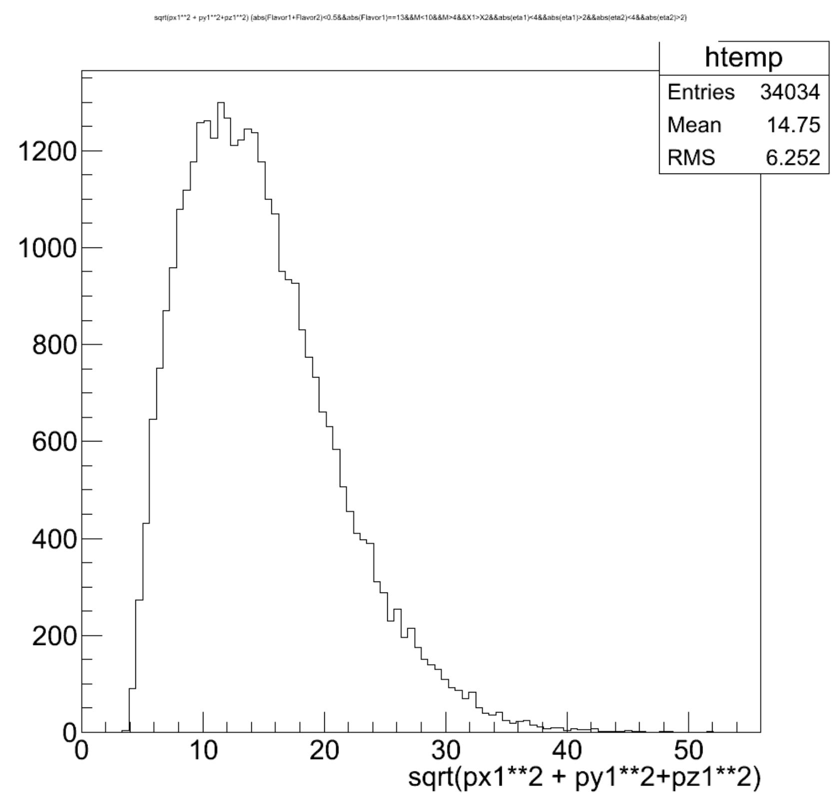
PYTHIA Sim: DY @pp200GeV

4 < Mass < 8 GeV & 2<η<4

- X1



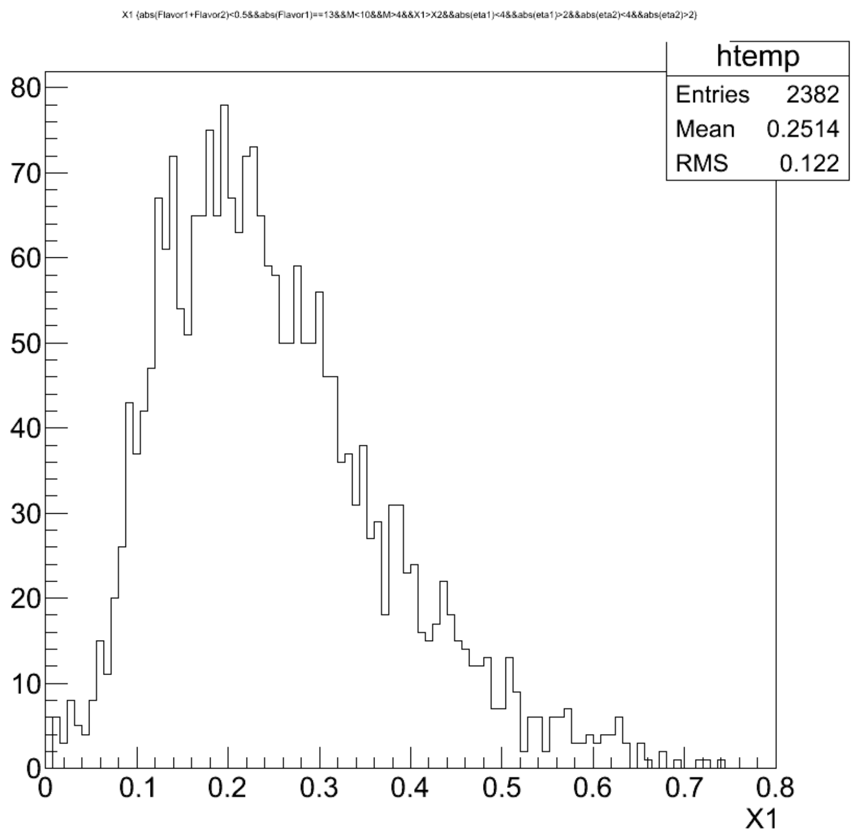
- Track P_tot range (GeV)



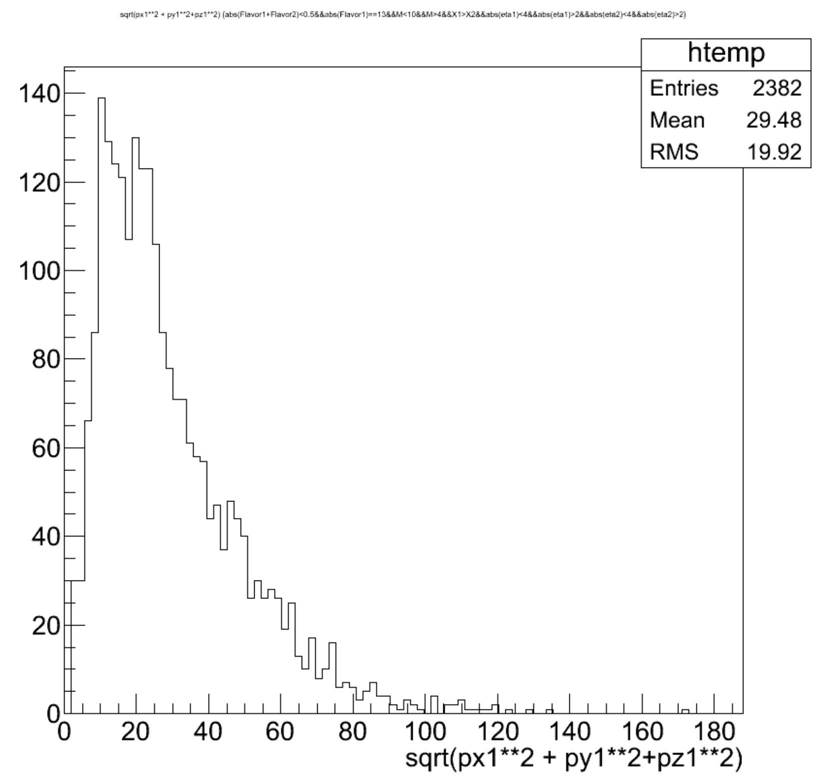
PYTHIA Sim: DY @pp 500GeV

4 < Mass < 8 GeV & 2<η<4

- X_1 range



- Track P_tot range (GeV)



Momentum Resolution Needed:

- X_1 resolution in Drell-Yan:
  - Goal: dX/X ~< 10%. (pict eta=3.4, p~ 30 GeV for example.)

$$P_Z \approx x_1\sqrt{s}/2 = p_{Z1} + p_{Z2}; \quad x_1 >> x_2$$

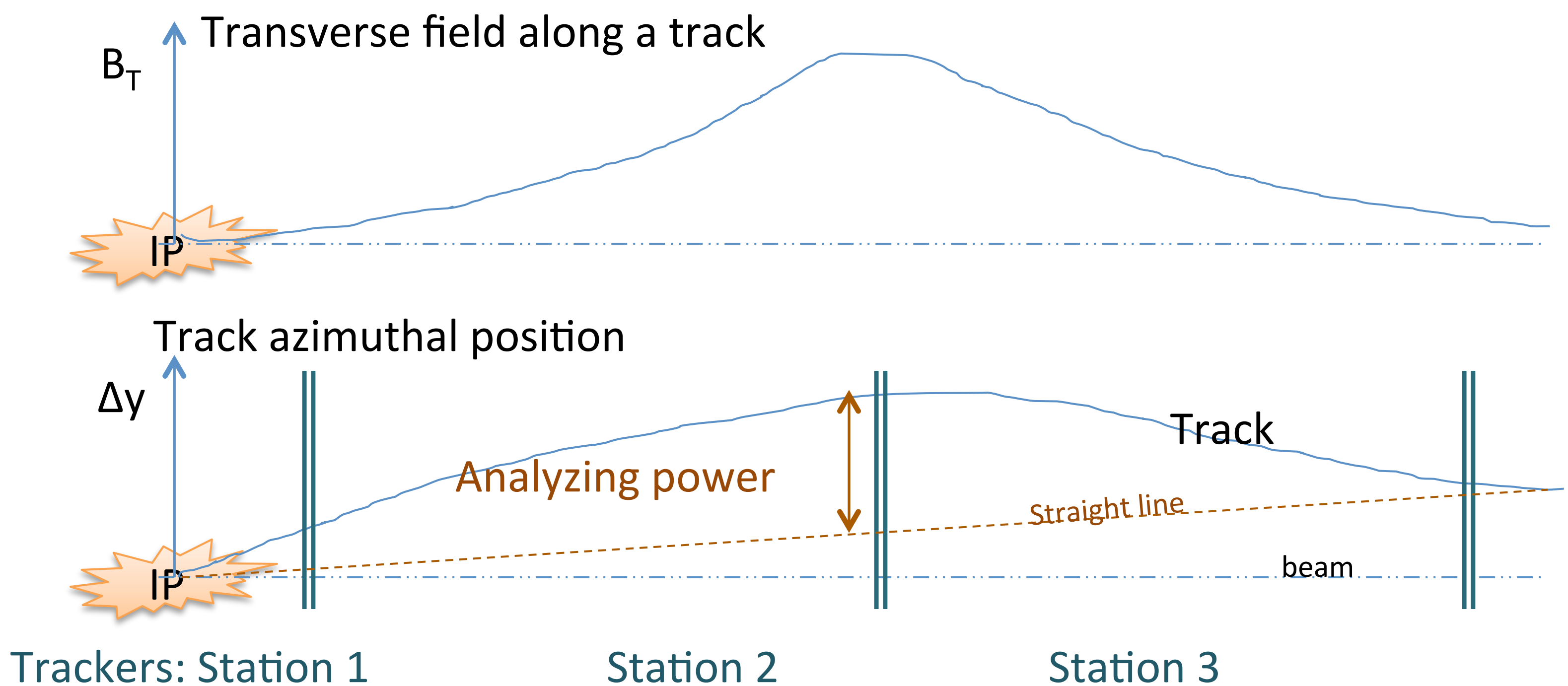
$$\frac{\delta x_1}{x_1} \approx \frac{\delta p}{p}$$

For forward W-> e decays:

Up to p_tot ~60 GeV, eta = 4

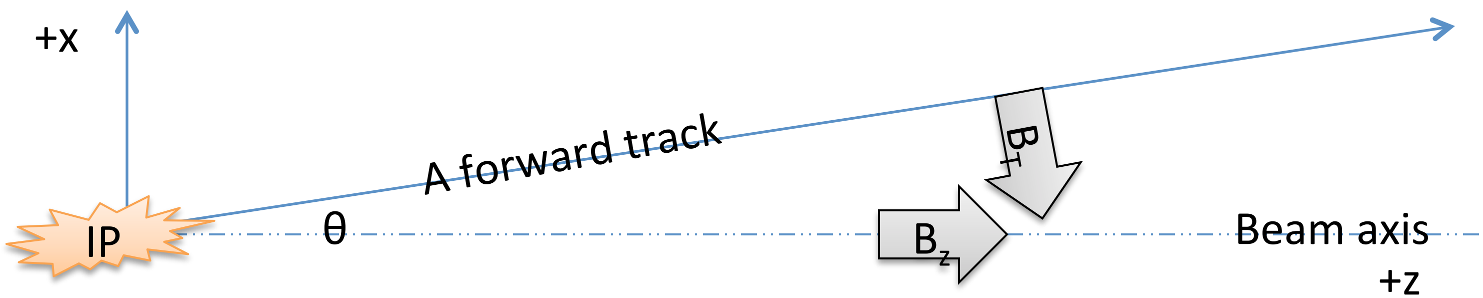
Require charge sign separation: >3 sigma

What transverse field we want?



- Transverse field (B_T) provide azimuthal bending and therefore momentum resolution
- momentum resolution ∝ (tracker resolution)/(spacing between stations)
  - Want max bending (and BT) in the middle of tracking region
  - Should keep three stations as far away as possible

The Math for azimuthal sym. field



Transverse field is directly related to shape of central longitudinal field:

$$B_T = B_z \tan\theta + \frac{\tan\theta}{2} z \frac{\partial B_z}{\partial z} + O\left(\theta^2\right)$$

Geometry Term

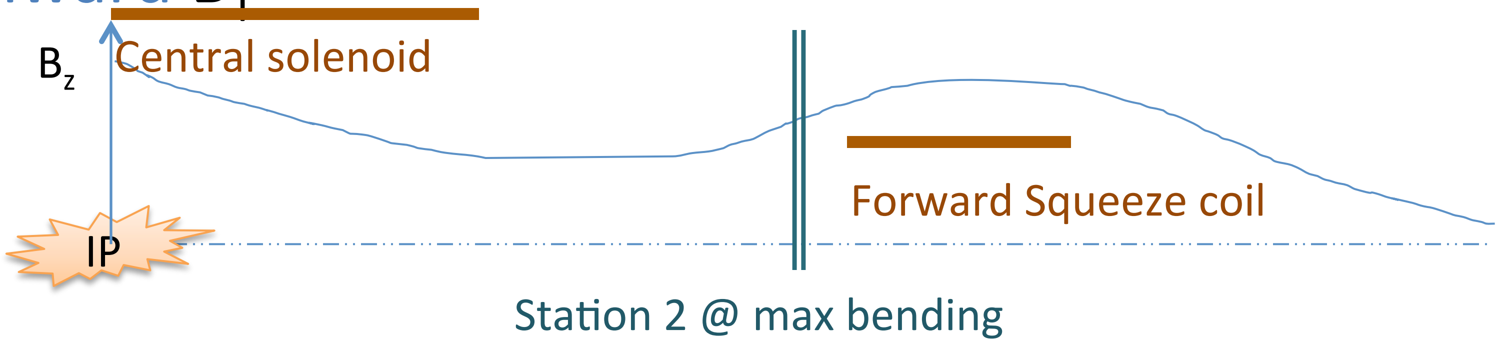
Flux Term

Two way to optimize transverse field, B_T

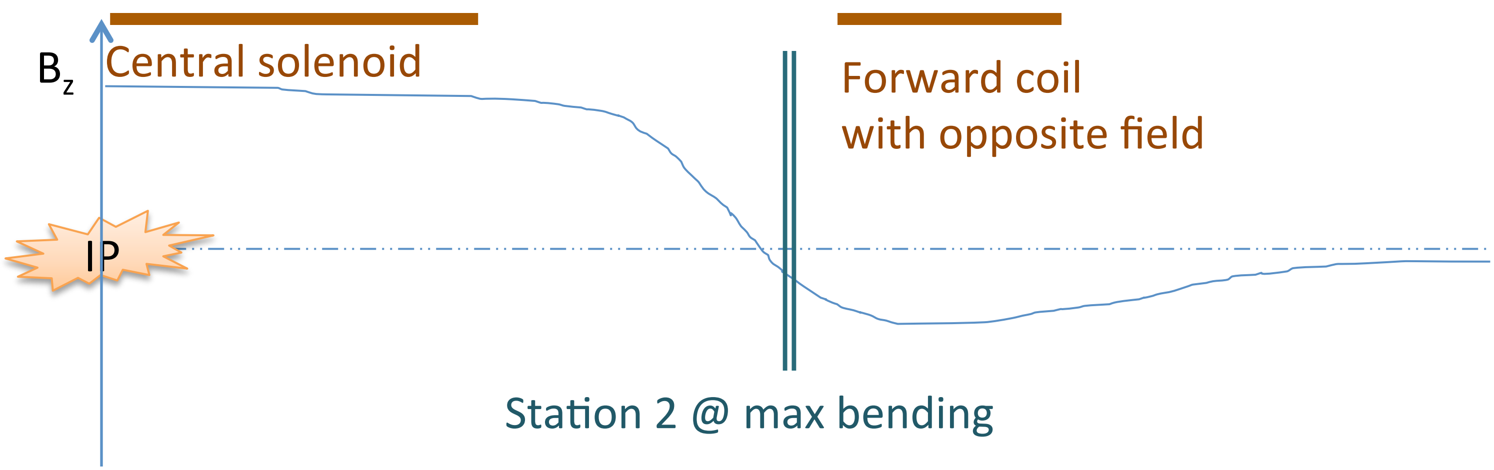
1. Maximize inward B_T at sensitive region
   - Need a squeezing coil
2. Maximize outwards B_T at sensitive region
   - Need a coil with opposite field

Optimal field for both options

- inward B_T



- outwards B_T

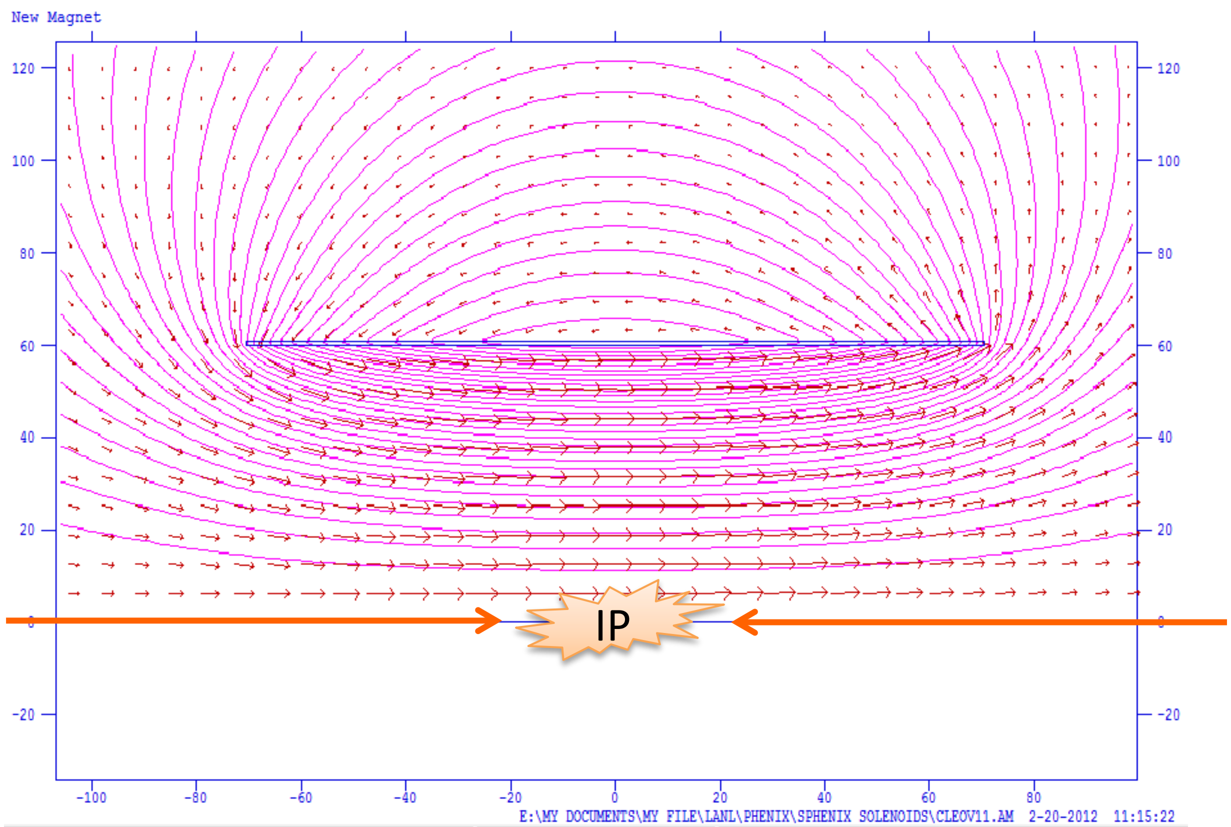


Numerical evaluations

- Transverse bending of tracks -> Choice of tracker
  - Resolution requirement
  - Where to put the detector
  - Number of layers
- In study …
  - Baseline: bending for a typical forward track with bare solenoid
    - Studied today with eta=3.5 and p=30 GeV/c
  - Try: what we can do to improve the field
    - Shape the magnet field with yoke/endcap design
    - Change the current density VS z in the solenoid
    - Other tricks?
- Quantitative tools
  - C++ track evolution code developed by Joe
  - Poission + Matlab by Jin
  - Under crosscheck

Baseline: what can a bare solenoid offer us?

- Assume a simple bare solenoid:
  - R = 60 cm, Length = +/- 70cm, Cover η<= 1
  - Central field, B_0 = 2T (@ z=0, R=0)

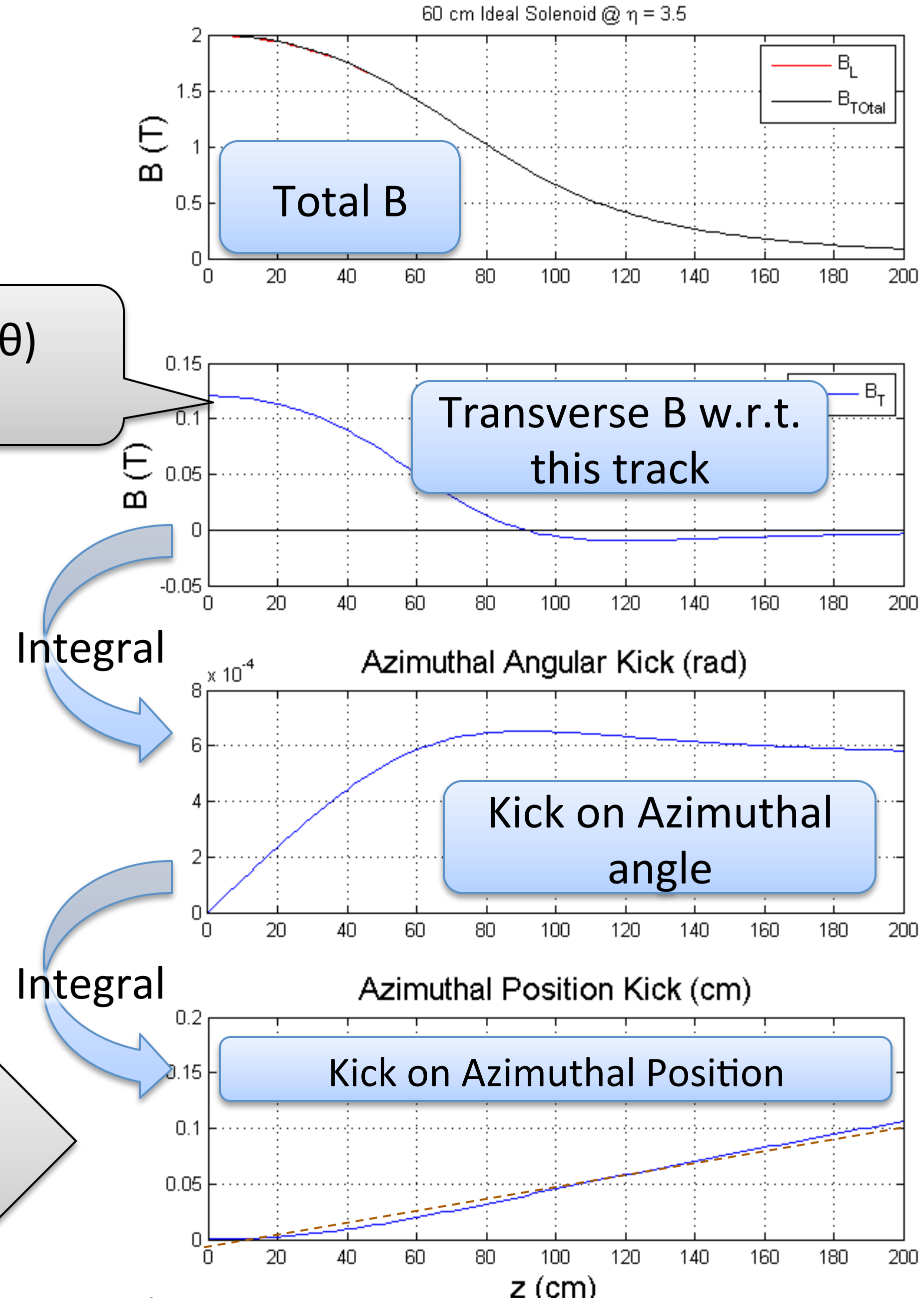


Field/Track

$B_{T\ (z=0)} = B_0\ \mathrm{Tan}(\theta)$
Always

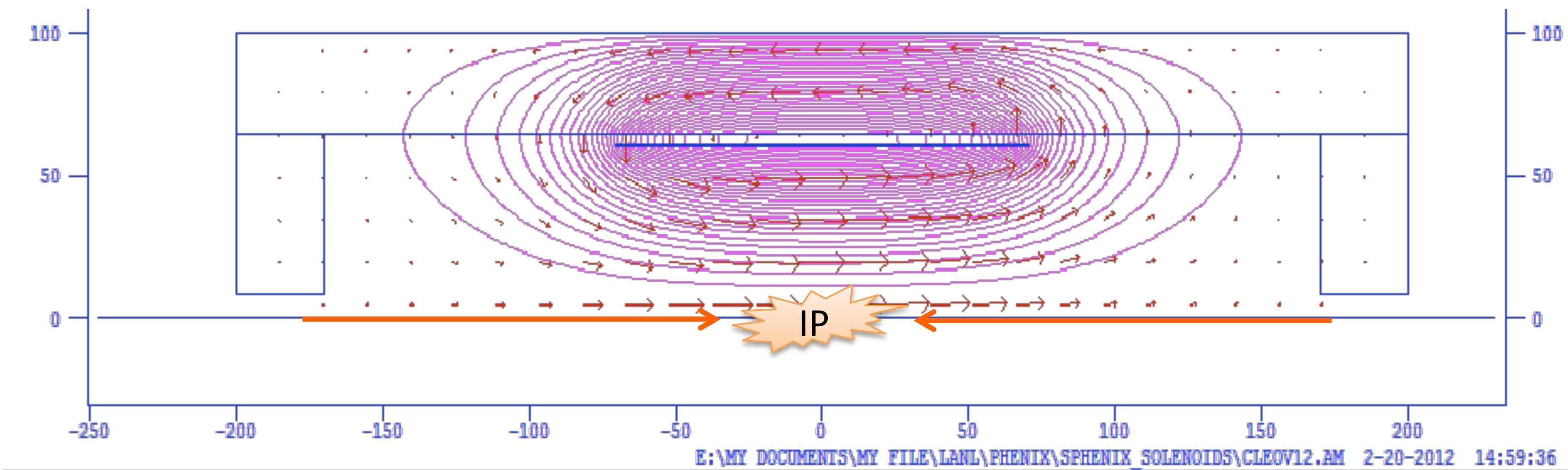
- For a typical challenging forward track:
  - p_{Total} = 30 GeV
  - Eta = 3.5
  - Starts from central IR

Most important for Tracking



What a simple return yoke do?

- A simple and long return yoke w/ end cap
  - R = 0.6 m, L_z = +/-2.0 m
  - Field shape do not change much for wall -> 4m

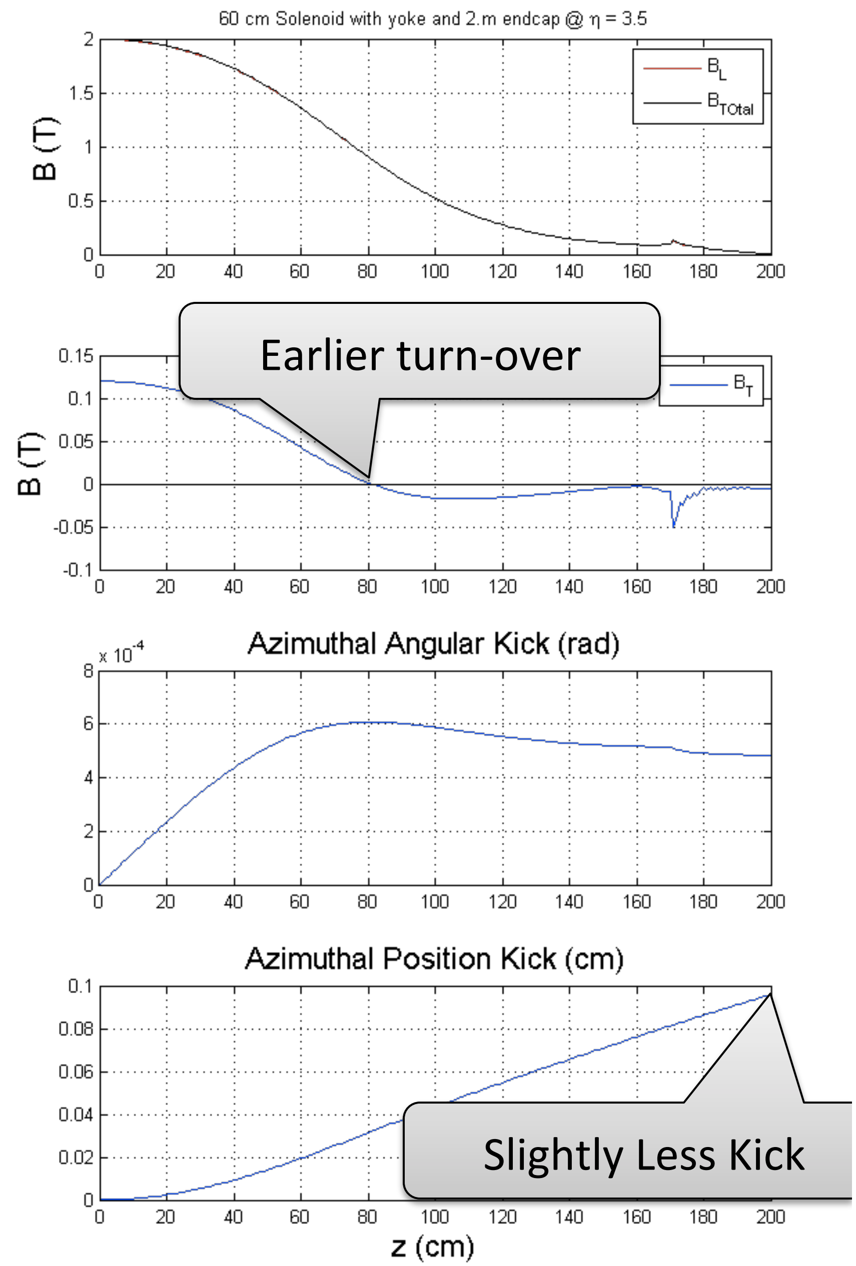


  - Most field line can not reach end cap!
    -> a far-away end cap do not affect tracking

Put in the track

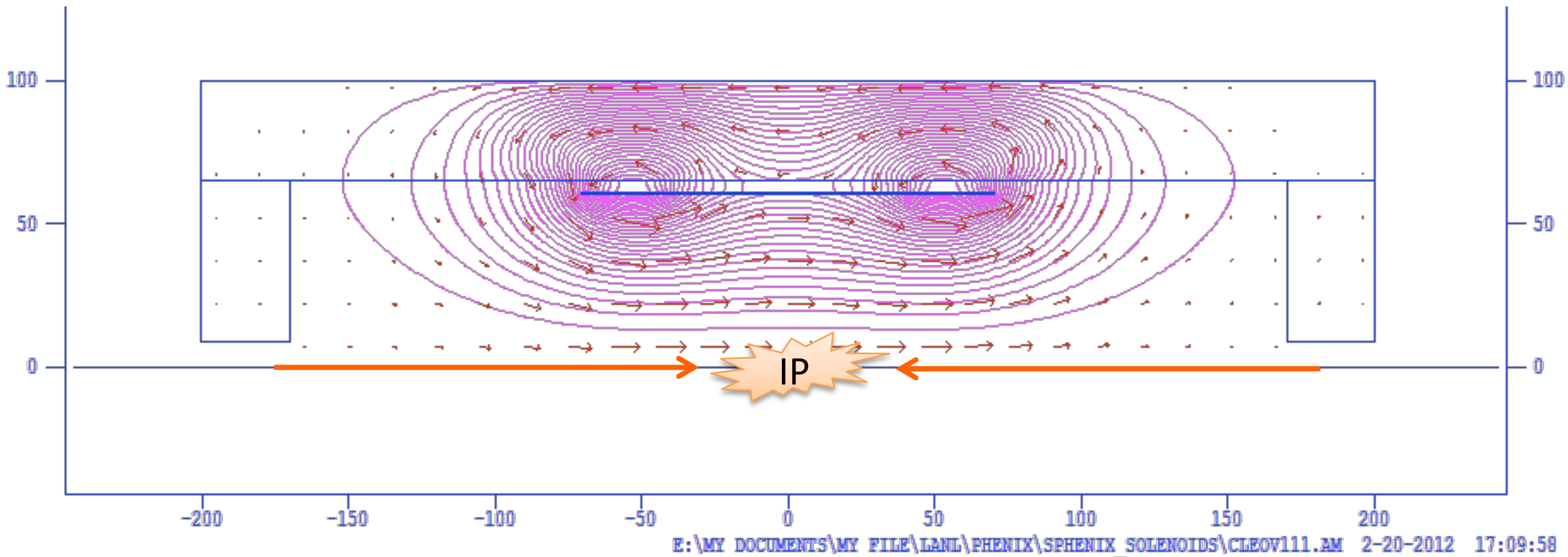
30 GeV @ Eta = 3.5

- Fish effect is larger
  - Make tracking slightly more difficult tracking
- Yoke have little effect on central field
  - little effect on tracking
- A nose cone may help



Solenoid with varying current vs z

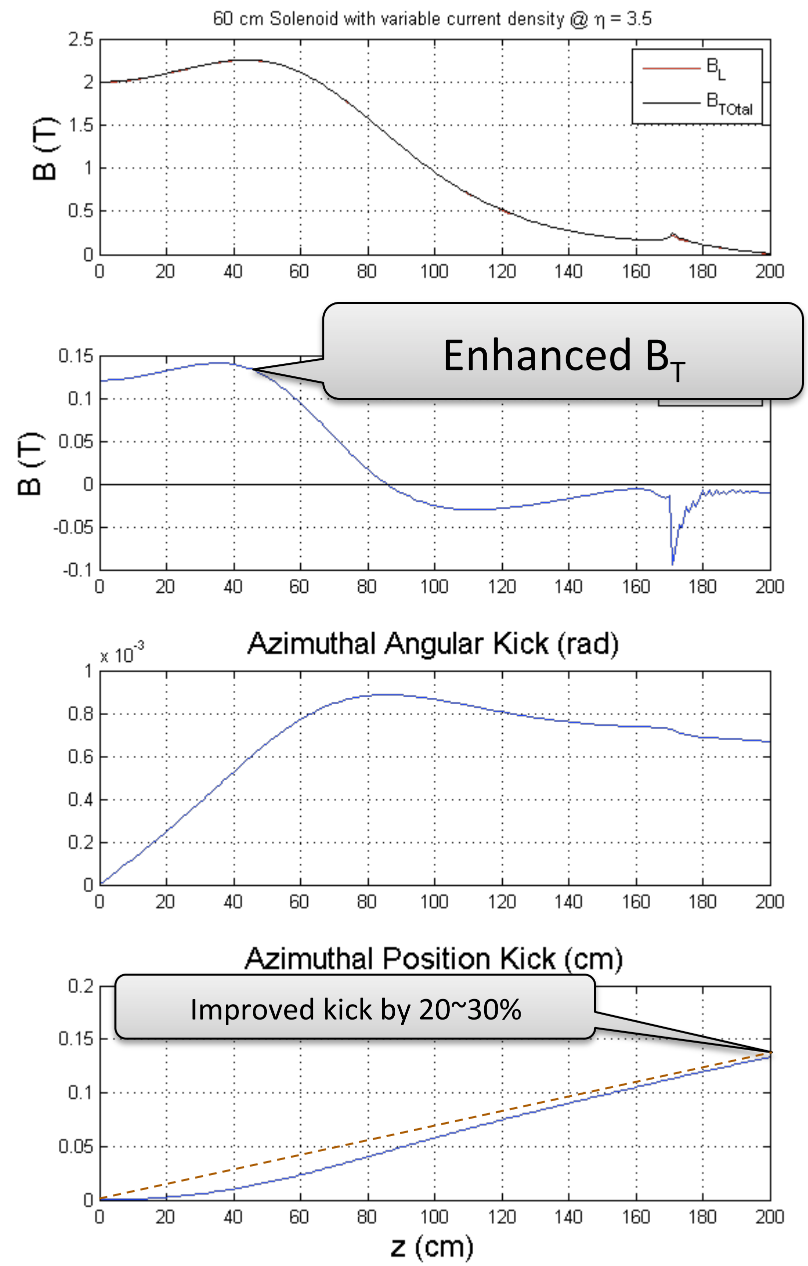
- Goal is to maximizing B_T in the center region
- What happen in the fringe field have little to do with tracking
- New solenoid : current density on the end is twice than that in the center



Simulate a track

30 GeV @ Eta = 3.5

- Enhanced transverse field (B_T) at central region
- Azimuthal kick increased by 20~30% (so does resolution)
- Can further improve B_T*ΔL if the solenoid is longer



Technically possible for varying current vs z?

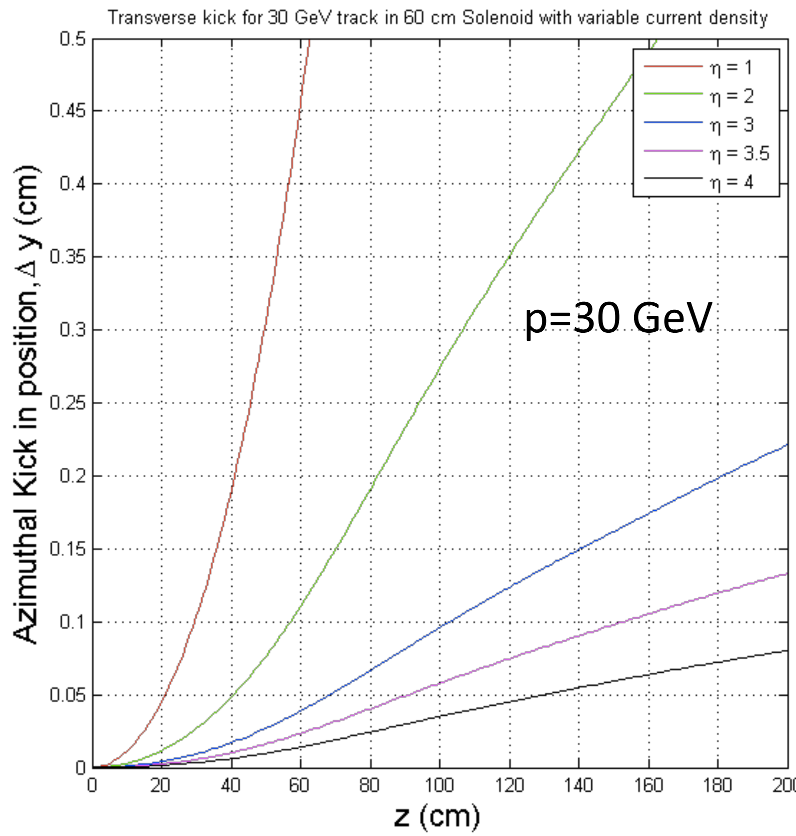
- Many solenoid have this feature to manipulate field
  - **Babar** : ~100% more current at the end
  - **CLEO** : ~50% less current at the end
  - **ZEUS** : ~25% more current at the end

What are the impacts to the central barrel jet reconstruction ?

- How much are we allowed to alter the magnetic field configuration in order to produce enough transverse kick at forward angles ?
- What are the criteria of making such a judgment ?

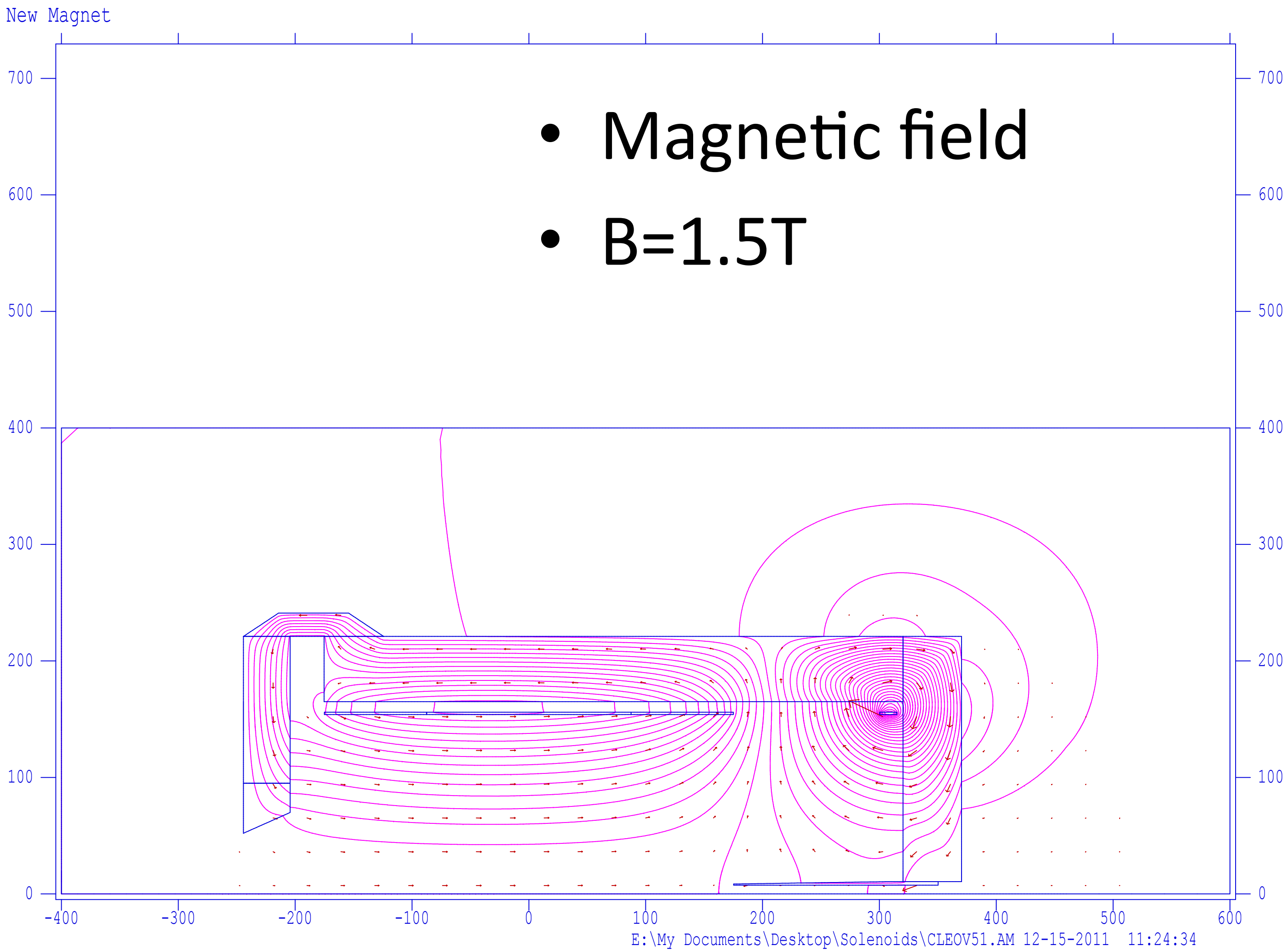
What happens to other tracks

- Transverse kick (shift in position) is proportional to 1/momentum
- Large eta always more challenging
  - Shown for 30 GeV ->



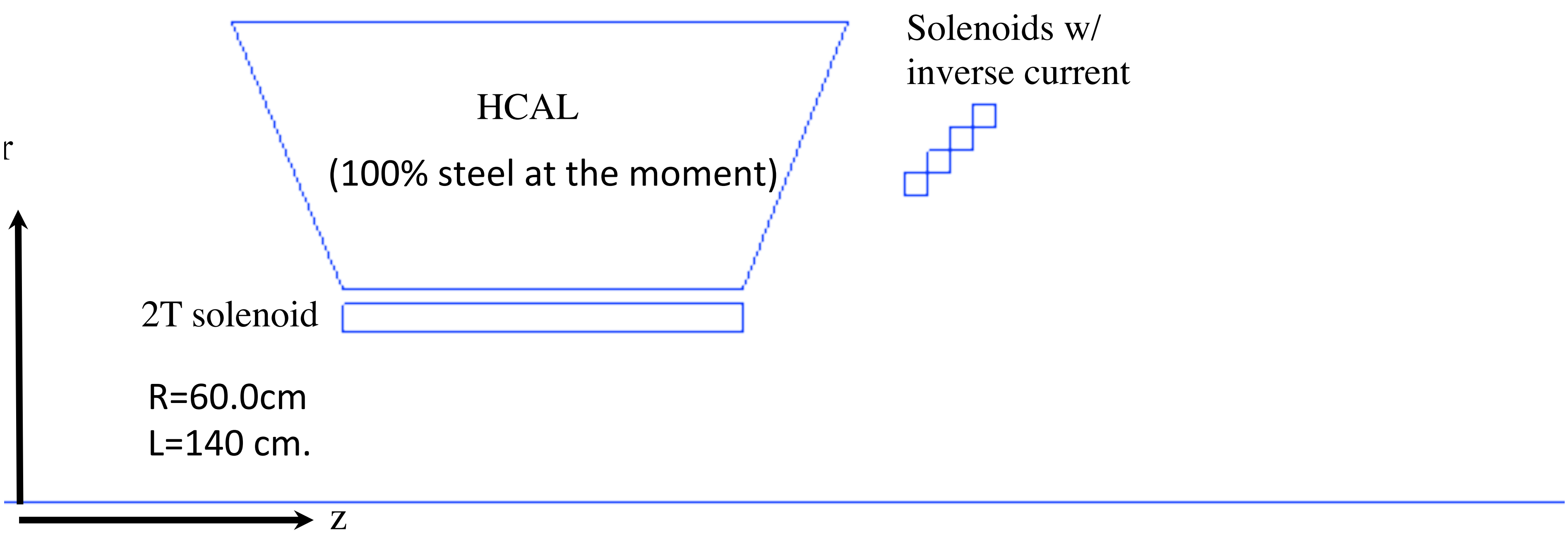
CLEO Magnet

CLEOV51

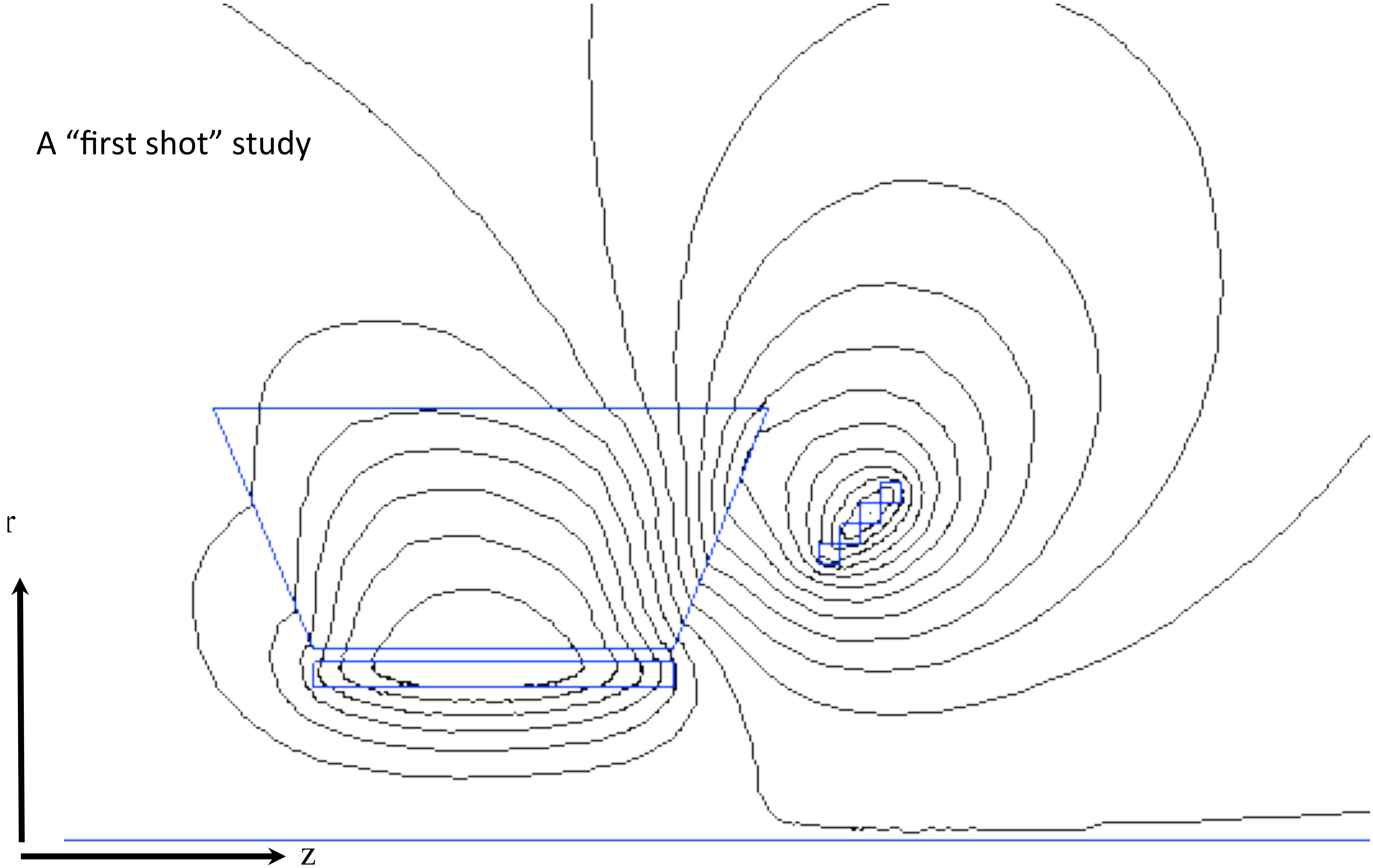


- Magnetic field
- B=1.5T

A "first shot" study

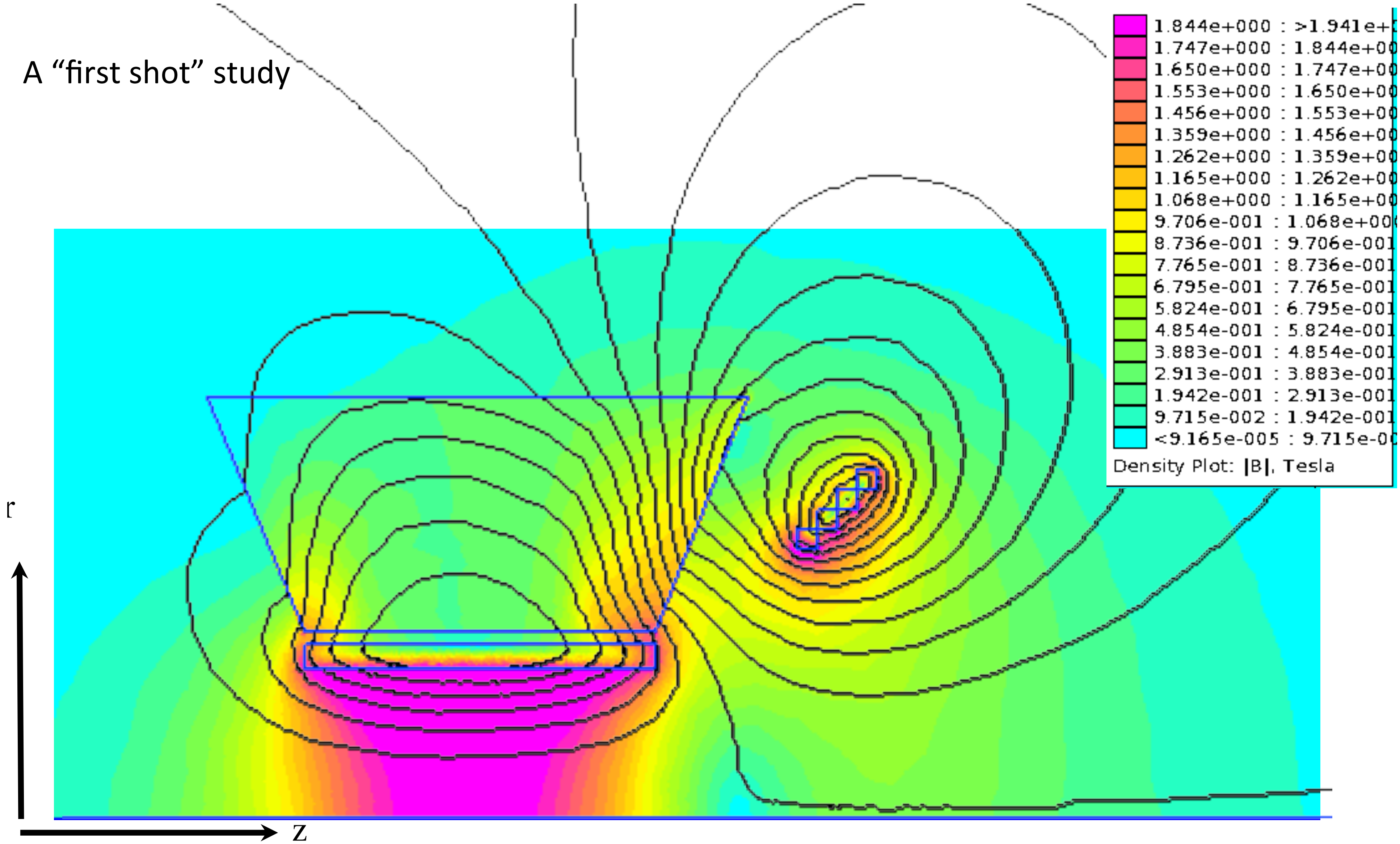


A “first shot” study



Cesar et al.

A “first shot” study



Cesar et al.

In progress, an internal LANL LDRD-ER proposal

• experiment and theoretical effort in forward physics (emphasis in CNM and HI)

• to build and test a forward tracker prototype and development for baseline physics sensitivities.

We currently favor developing a GEM based tracker (followed by an EMcal):

- resistant to radiation
- 50-100 micron position resolution
- take advantage of recent experience in HBD, even hardware prototypes.

Cesar et al.

Benchmarks:

- resolve Υ1S from Υ(2S+3S) at η=3
- charge separation of a 50 GeV/c track at η=4
- affordable occupancy in central Au+Au collisions for η<3

Physics goals for day one

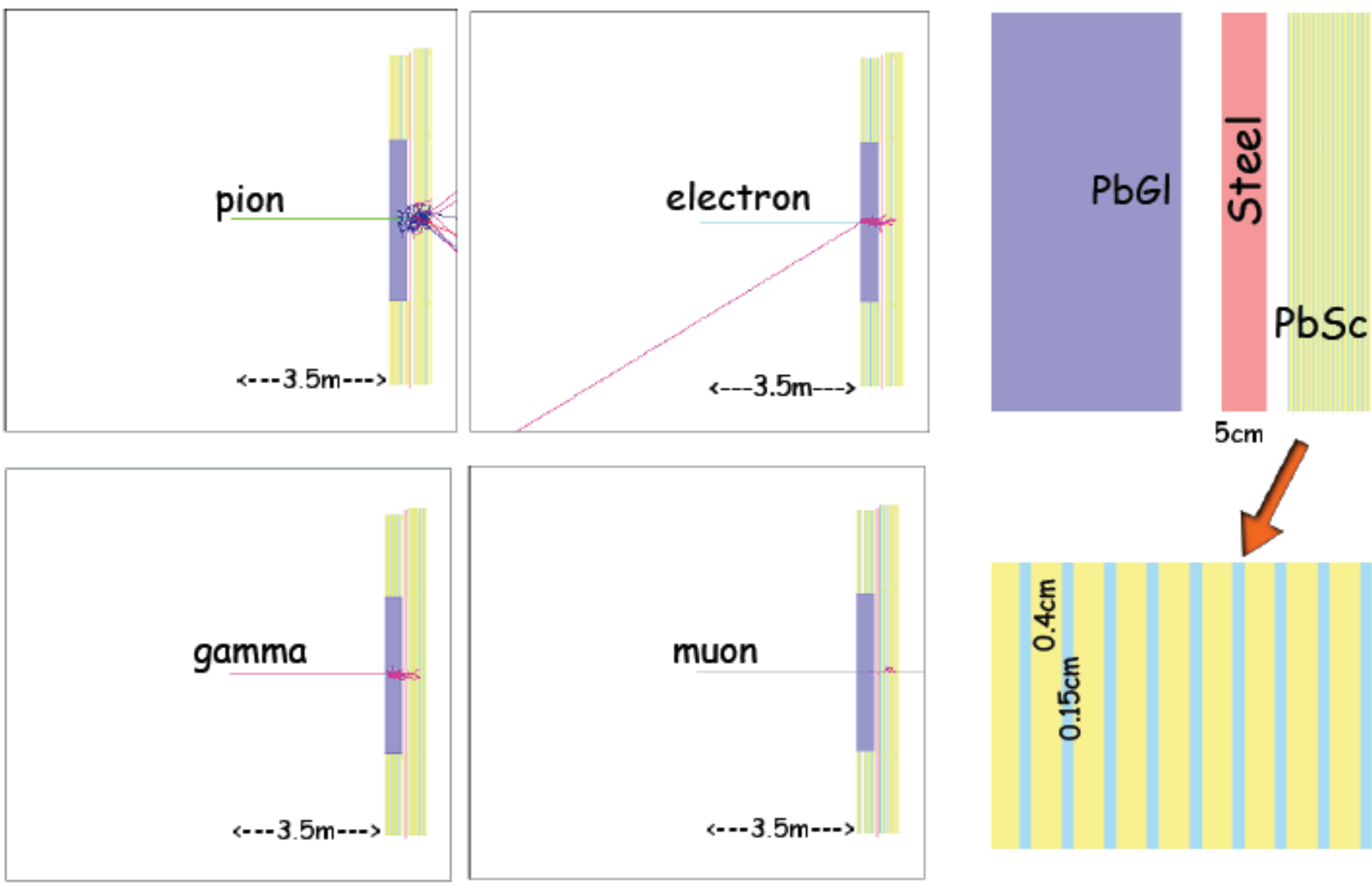
- $dE_T/d\eta$
- π^0
- Heavy flavor correlation physics (with FVTX 1.2<η<2.4)
- quarkonia (J/ψ, ψ' , Υ1S, Υ2S+3S)
- direct photons (η<2)
- Drell-Yan (spin)

Occupancy studies

- studies started with current PbSc and PbGl placed at Z=3.5m
- thrown HIJING events on 5cm x 5cm segmented wall returned occupancies of up to 100% for $\eta \sim 3$
- but not all these particles should reach the wall and PbGl and PbSc can have zero suppression adjusted
- PbGl and PbSc now are implemented in GEANT4

EMCal coverage: $0.8<\eta<4$

$p_T=0$ $p_Z=2$ GeV/c



with MPC-EX Emcal close to beam pipe.

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In the next few months:

- settle magnetic field configurations.
- p+p, d+A and A+A forward simulation for single particle yields.
- Pass through GEANT4 model to obtain single particle rates at the detectors.
- Tracker performance specifications.

Summary

Working to define forward detectors for:

- magnetic field configurations.
- momentum resolutions for tracker.
- Simulations for detector rates study

Request LANL internal funding to build a forward prototype detector.

The task force agreed to start working on a **brief summary** document of "sPHENIX-Forward Physics Motivations and Detector Specifications".

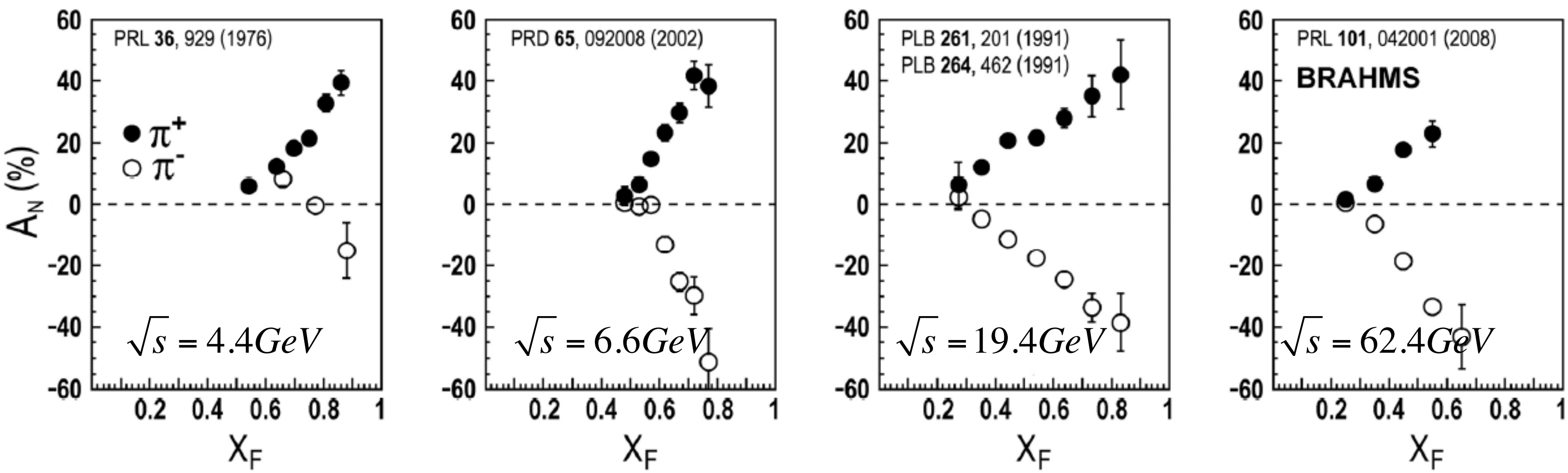
- Transverse spin (p+p).
- Heavy Ion (A+A).
- Cold Nuclear Matter (d+A).
- (p+A and polarized p+A).

- Tracker (GEM ?)
- Tracker (diamond pixel ?)
- Hcal
- Emcal
- RiCH

Backup Slides

Inclusive Hadron SSA

Large, forward A_Ns in hadron production in p+p (p+A) have been measured since the mid 70's



The asymmetries persist from low CM energies to high CM energies.

$$x_F = \frac{2p_L}{\sqrt{s}}$$

A simple (collinear) pQCD calculation tells us that an A_N can exist, but that it should scale like

$$A_N \approx \frac{m_q \alpha_S}{p_T}$$